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CRASH INJURY

By Gerard J. Pesman and A. Martin Eiband

Lewis Flight Propulsion Laboratory
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SUMMARY

Data from full-scale experimental airplane crashes were studied to determine how impact injuries occur and how the chance of such injuries may be reduced. The following hazards were considered: (1) being crushed, (2) being struck by missiles, (3) striking objects by tearing loose or flailing about, and (4) being injured by the crash decelerations. Transport, cargo, fighter, and light airplane crashes were studied.

INTRODUCTION

People involved in an airplane crash can be injured by the crash impact or by a fire that may result from the accident. The hazards resulting from the fire were appraised by studying data obtained as part of a full-scale experimental crash fire program. Some information about the hazards resulting from the impact was also obtained during that program and is reported in reference 1. In a more recent program additional airplanes were crashed to determine how impact injuries occur and how the chance of such injuries may be reduced. This material is the subject of the present paper.

In general, impact injuries come about in four ways. (1) The fuselage may be collapsed by the crash impact and the occupants trapped or crushed. (2) The impact forces may be violent enough to tear cabin equipment loose and hurl it through the cabin to strike people. (3) The people themselves may move and be thrown against the seat belt violently enough to break either the belt, the seat, or seat attachment fittings. The detached people and seats can then be hurled against obstacles in their paths and the people injured. If the belt, seat structure, and attachments are strong enough not to fail, the people can still flail about and strike nearby objects. (4) Even though not injured otherwise, people may still be injured by the sudden rapid deceleration of a crash impact. The study of experimental crash data in conjunction with a study of actual crashes provided information on all four impact hazards. The experimental crash studies included transport, cargo, fighter, and light airplanes; thus the results described should apply generally to all airplanes.

CRASH PROCEDURE AND INSTRUMENTATION

The facilities and procedure used for the experimental crashes are completely described in references 2 and 3. Briefly, the procedure was as follows: The unmanned airplane was guided along a runway by slaving the front wheel to a steel monorail in the center of the runway. The airplane's engines accelerated the airplane to approximately take-off speed by the time it reached the end of the 1700-foot runway. At the end of the runway, the airplane ran into specially prepared barriers and obstacles that produced the desired crash events. Unflared-landing, ground-loop, and cart-wheel crashes were studied. These crashes imposed upon the dummy occupants of the airplanes essentially the same crash conditions as those to which airplane occupants are exposed in an accidental crash.

The airplanes were manned with dummies to load the seat structures and the restraining harnesses. Anthropomorphic dummies were used where the dummy could move and its motion affected the resulting loads. Where the motion was not a factor, rigid dummies whose mass distribution was similar to that of a human being were placed in the seats. The accelerations of the airplane, seats, and dummies were measured. Loads imposed on the restraining harnesses by the dummies during the crash impact were also measured.

The motion of the airplane during the crash was recorded from several directions by high-speed motion picture cameras so that it could be studied in detail. Where possible, motion pictures inside the airplane were taken of the dummies' action. The motion pictures, the acceleration and crash loads data, and a postcrash examination of the wreckage provided the experimental data upon which this study was based.

RESULTS AND DISCUSSION

Crushing is the first hazard discussed, since the occupants of an airplane must survive or be protected from this hazard before the remaining hazards need be considered.

Crushing of Occupied Zones

If an airplane strikes the ground or a large obstacle and the impact loads are greater than the ultimate strength of the fuselage structure, then the fuselage crushes. The amount of the fuselage that crushes depends on the kinetic energy that must be extracted in stopping the airplane (ref. 3). An example of such crushing is shown by figure 1. In that experimental crash, the airplane was flown across a ditch and into a mound of earth with an impact angle of 30° (an angle of 30° between the airplane's trajectory and the ground surface). The airplane speed at the instant of impact was about 110 miles per hour. The photographs of figure 1, reproduced from a motion picture of the incident, show a succession of steps in the crushing action. Figures 1(a) to (c) show that the fuselage structure was not strong enough to noticeably deflect the airplane from its original path; the fuselage crushed continuously. When the stronger wing and engine support structure struck the ground (fig. 1(d)), the airplane's path was changed until the airplane was moving parallel to the ground and the crushing action stopped. By that time, however, every part of the fuselage structure ahead of the wing, including the cockpit, had been crushed. If the angle of impact and impact speed are great enough, any airplane will crush in a similar manner. Survival under such circumstances is improbable.

If the angle of impact is decreased, and the airplane has a stronger floor structure located well above the airplane's belly, then the occupied zones are less likely to be crushed. The action of an airplane structure under these circumstances was studied by the experimental crash of a cargo airplane. In this experimental airplane the crew compartment was located in the upper part of the fuselage ahead of the wing and had a strong floor structure that extended the full length of the compartment. Other parts of the nose structure, however, were less sturdy.

The action of this cargo airplane structure during a crash impact is shown by the sequence of photographs in figure 2. When the nose of the airplane struck the ground, the weak understructure crumpled until the floor of the crew compartment was reached (figs. 2(a) to (c)). The strong floor structure prevented further crumpling. Instead, the crew compartment hinged upward, lifting at the front and hinging at a point near the wing leading edge (fig. 2(d)). The hinging action lifted the compartment so that it was not in the direct line between the main mass of the airplane and the ground. The compartment thus was not subjected to the total force decelerating the airplane and consequently was not crushed.

The hinging action apparent in the crash just described might be deliberately emphasized in designing the airplane structure. The general principle is indicated by figure 3. It is not implied, however, that the structure should be constructed as shown. If the forward compartment is so constructed that it is essentially a cantilever structure with a strong floor, then it can support and lift the occupants (fig. 3). If the compartment is also designed so that it can hinge at a point above the leading edge of the wing (point A), then the compartment can hinge and lift. The bottom members (at point B) should be connected to carry the front-landing-gear loads but should be weak enough to break when a crash impact occurs. Deliberately applying this principle in the design of an airplane would be difficult because of conflicting structural requirements. Any compromise, however, that would favor this hinging-lifting principle would be one step that would help to reduce the crushing hazard.

Although hinging action would help to protect the occupants during the initial impact, there is an additional problem. As the airplane slides along, it tends to ride up and over the crumpling lower structure. Since the lower structure is fastened to that above, the upper structure is also pulled down and under the sliding hulk. In the crash of the cargo airplane, however, the strong floor structure of the crew compartment combined with the weaker lower structure allowed the metal to tear at the floor line. Consequently, the crew compartment was not pulled down and under as was expected. The undertow and tearing action are apparent in figure 4. Figure 4(a) shows the nose of the airplane just before it touched the ground. Soon after the first impact (fig. 4(b)) a large wrinkle had formed in the fuselage skin (point A), and the parallel lines painted on the nose were bent showing that the nose structure was being pulled down. An instant later (fig. 4(c)), the understructure had been crushed up to the bottom of the Y painted on the side of the fuselage. The nose structure had separated from the main bulkhead (point B). Crushing of the understructure and pulling under of the nose structure progressed rapidly (fig. 4(d)) until the understructure was crushed and torn away almost up to the floor level (point C, fig. 4(e)). The nose section had been pulled completely under the sliding hulk.

When the understructure does not tear along the floor line, then the occupied compartment can be pulled under the sliding airplane. This action is shown by figure 5. Immediately after the initial impact, the nose section of the airplane back to the front cockpit bulkhead crushed, lifted, and then broke free. The lower edge of the cockpit then dug into the ground and the cockpit began to pull down and under the airplane.

When the airplane had stopped, the cockpit appeared as in figure 6. The remains of the detached nose wreckage are shown at the right, the cockpit wreckage, wings, and part of the fuselage on the left. Figure 7 is a closer view of the cockpit zone. Part of the cockpit structure had been pulled under the airplane. The dummy's head, one shoulder, body, and one thigh can be seen. From the dummy's position, it can be seen that it would also have been pulled under if the airplane had continued to slide. Comparison of the crushing action in this crash with that in the cargo airplane crash shows that if the forward fuselage structure is designed to tear free below the floor line, as well as hinging and lifting, the crushing hazard is further reduced. This principle is shown by figure 8. Again, the figure portrays the principle, not a suggested structure.

Deliberately incorporating the lifting-hinging and the tear-line principles may not be practical. If any choice is possible, however, the design that permits the fuselage to hinge up during the initial impact and that permits the structure to tear free at the floor line should be favored.

The crushing just discussed is caused by the forward motion of the airplane. If the airplane slides sideways, or ground loops, then large side loads are applied to the fuselage structure. Most transport airplanes have a circular or oval cross section that can resist these side loads rather well. Airplanes that must use a rectangular cross section usually cannot carry heavy side loads. The fuselage framing collapses sideways and crushes the occupants. An example of such collapse is shown by figure 9. The airplane ground looped during the experimental crash. The heavy steel instrument box seen through the rear door kept the fuselage from collapsing completely.

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The collapse of secondary structures such as seats, or the partial collapse of the cabin structure, can also threaten survival. Occupants can be trapped or pinned in the wreckage although they may not be severely injured. An example is shown by figure 10, which shows a side view of a light-plane fuselage after an experimental crash. The dummy's foot was pinned in the wreckage by the buckled strut. Its foot was bent up nearly parallel to its shin. A person in similar circumstances would not have been severely injured, but escape would have been impossible, and rescue would have been difficult. If such trapping occurs during a ditching or crash fire, the results might be fatal.

Missiles

Even though the crash forces to which an airplane is exposed are not large enough to crush the structure, the forces may still be large enough to break the attachment fittings for equipment like fire extinguishers. Such detached equipment or other loose articles become missiles inside the cabin because of their inertia. In one of the experiments, when motion pictures were being taken inside the cabin while the airplane was crashing, a record was obtained of such an event. Figure 11 shows several frames from this motion picture. An escape hatch is shown being thrown across the cabin by the impact and striking a dummy.

Similar incidents occur in actual accidents. During one crash, the fire extinguisher held by brackets on the bulkhead hit the stewardess seated at her normal place and knocked her unconscious (fig. 12). This hazard can be readily eliminated by designing the brackets for such equipment to withstand the crash impact loads.

The front landing wheel assembly and the propellers can also produce missiles that may enter occupied zones. If a nose wheel is torn off by an obstacle, it can be driven back into the airplane, or it may be tangled with the debris under the belly and work its way through the floor. The results of such an incident can be seen in figure 13. This view was taken looking forward in the fuselage. The nose gear entered the fuselage a few feet behind the main forward bulkhead. The nose wheel strut can be seen protruding from the floor.

A closer view of similar wreckage is shown by figure 14. In this view, the observer is looking down at the landing-gear strut and the hole through the floor. The forward bulkhead is shown at the top of the figure, the scuff strips on the floor at the bottom of the figure. The landing-gear strut, the axle, and the guide slipper that replaced the front landing wheel in these experimental crashes can be seen protruding from the hole in the floor.

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Propeller blades and fragments of blades that are broken off when propellers strike an obstacle can appear as missiles inside the airplane. The action of steel propeller blades is shown by the photographs in figure 15. Three propeller blades were detached from the propeller hub (fig. 15(b)) and cut through the fuselage (fig. 15(c)). They can be seen against the sky in figure 15(d). An indication of the damage such missiles can do can be gained from figure 16, which shows the holes cut in the fuselage walls. Each opening is about 1 foot wide and 4 feet high.

Although these missiles are obviously dangerous, fortunately the penetrations usually lie within an angle of about 30° of either side of the propeller disk. Figure 17(a) shows the paths of the detached propeller blades for four experimental crashes. The results from figure 16 agree with those shown by figure 17.

Forged aluminum propeller blades break off at the tips instead of twisting out of the hubs. Each blade can produce one, two, or even three missiles. These fragments scatter over a wider angle because they are of smaller mass and are thus more easily deflected when the blade strikes the ground. The paths of these fragments during 14 crashes are shown by figure 17(b). Few of the fragments have enough kinetic energy to go through both fuselage walls. Fragments deflected through a large angle when striking the ground would be more likely to glance off the fuselage walls instead of cutting through.

The hazards of both landing gear and propeller parts as missiles can be reduced by locating the baggage holds, the galley, and coat-rack and toilet compartments in the usual paths of these missiles (fig. 18). Some aircraft manufacturers have adopted this idea to a limited extent. The propeller blade hazard can also be reduced by reversing the direction in which the right-side propellers turn. This remedy is discussed in reference 1.

Obstacles

Thus far the hazard of occupants being struck by flying objects has been considered. Injury is also possible if the people themselves move. During a crash, a person held by a seat belt alone flails about and strikes objects near him. His hands, feet, and upper torso swing forward; his chest strikes his thighs; and then his head snaps down. This flailing action is shown by a sequence of photographs taken during an experimental crash (fig. 19).

The objects a flailing person can strike depend upon his physical size and the belt stretch. The belt stretch can be several inches. Consequently, several objects such as a seat back, cabin wall, instrument panel, or control stick may be within the range of a large person's flailing motions. Breaking arms or legs by striking an object although painful is seldom fatal. A skull fracture, however, is a serious injury.

A human skull, striking a solid surface with a kinetic energy of 600 inch pounds will be fractured (ref. 4). Since a person's head weighs about 10 pounds, a velocity of only 18 feet per second provides a hazardous energy level. In the crash of figure 19, the dummy's head was traveling about 67 feet per second when its chest hit its knees. Consequently, there was 14 times the minimum energy needed for a fractured skull. To eliminate part of this hazard, the seat backs of several present day airplanes are hinged to swing forward or are made of easily deformed metal. Some deformed seats from an actual accident are shown in figure 20. Each arrow points to a place where an occupant hit and deformed the seat back thus being spared more serious injury. Figure 20 and most of the photographs that follow were furnished by the Aviation Crash Injury research group of Cornell University.

This group is studying the importance of head injuries. A preliminary study of 100 fatalities from 15 transport accidents has shown that 54 percent of the fatalities were from head injuries, and an additional 21 percent from a combination of head and upper torso injuries. Among the 136 survivors of these same accidents, 68.4 percent had head injuries.

If seat belts fail, or if the seats break loose, then the occupants instead of flailing about become free bodies inside the airplane. When this happens, passengers pile up in the front of the cabin. Figure 21 shows seats piled in the front of an airplane after the passengers were removed.

Wreckage from another accident in which many seats pulled loose is shown in figure 22. Broken seats could have been expected in front of the break in the fuselage (fig. 22(a)) because the fuselage structure was severely damaged. Aft of the break, however, the fuselage structure did not appear severely damaged, and little seat damage would have been expected. After the debris had been removed, the cabin appeared as shown in figure 22(b). The floor was badly deformed, and all the passengers' seats except the aft four had come loose (fig. 22(c)).

When people and seats are torn loose and become free bodies in a sliding hulk, they can strike sharp, pointed, or solid obstacles. Broken seat parts are examples of obstacles that can cut and puncture people as they are thrown about. An example of such a spear, a broken tube from the seat back, is shown in figure 23. A similar spear in the same crash produced a wound about 3 inches long that extended from the bridge of the victim's nose to beyond his eyebrow. The cross section was roughly semicircular and was about 1/4 inch deep.

If the seats remain fixed, but a belt fails, then a person's feet can slide under the seat ahead as shown in figure 24. The inertia of a person's body is applied to his shins with the seat structure as a fulcrum. A lower leg fracture is almost certain. Such injuries have occurred and can be avoided if the seat belts are made as strong as the seats. 4149

Crash Deceleration Forces

Even if the people and seats can be kept in their places, however, people may still be injured or killed by the crash decelerations. Hence, it is necessary to know what decelerative forces a human being can tolerate. The information available comes from both animal and human studies. A large part of the data are from Lt. Col. Stapp's high-speed sled studies.

Of particular interest are conditions in which the stopping force is applied perpendicular to the spine and parallel to and compressing the spine. Of interest also is the tolerance when the occupant is free to flex around the seat belt and the kinetics of his motion become a factor.

The tolerance to decelerative forces perpendicular to the spine are discussed first. The data for this position are summarized in figure 25. These data are for subjects held by a belt, thigh straps, a shoulder harness, and a chest strap. Although only forward-facing data are shown on this figure, other data indicate that the tolerance would be the same for the aft-facing position. In this figure, the acceleration of the seat is plotted against the duration of the deceleration, the duration being defined as the sustained plateau duration of the deceleration (see small inset in fig. 25).

Human subjects have voluntarily been subjected to decelerations of 45 G's for intervals up to 0.06 second. After exposure the subject was uninjured and was immediately able to go on with his work. When the duration was increased to about 1 second, the voluntary tolerance was decreased to about 12 G's. These limits apply when the G onset rate is 1500 G's per second or less. Onset rates below 1000 G's per second are preferable.

If minor injury, that is, injury such that a person can be up and about in a few days, is acceptable, the tolerance is raised to the dashed line (animal data). Pigs have been decelerated at 160 G's per second for 0.004 second. With increasing duration, the tolerance decreases to about 55 G's for intervals of 0.04 second (chimpanzee data). With maximum body support and a head support, Col. Stapp has tolerated 25 G's for a full second. On the basis of his experience, Col. Stapp has concluded that a triangular pulse having a peak value of 50 G's and a 0.2-second base value can be tolerated with only minor injury. Consequently, this threshold line could probably be revised as shown by the heavy line without serious error.

The human points at decelerations of 140 to 200 G's represent falls that were not fatal. Except for bones that were broken because extremities were unsupported, there was little other injury in these cases. These falls show that unless the body support is very complete, exposures above the dotted and revised heavy line will produce injuries that require relatively long growth processes to repair.

In addition to the horizontal crash loads, severe vertical crash decelerations also occur during crashes. These vertical decelerations impose compressive loads parallel to the spine. For this reason, the human tolerance to these loads must also be known. In figure 26, seat acceleration is plotted against duration of the pulse, the time duration again being the sustained plateau deceleration value. The restraining harness is basically a seat belt and shoulder straps for the lower curve. Sustained accelerations of 16 G's for an interval of 0.04 second have been tolerated without injury or shock. The tolerance then decreases to about 10 G's when the duration is increased to 0.1 second and decreases still further with longer durations. The data represented by the broad level line were obtained from a study of the compressive strength of the spine. In this study fresh vertebra were installed in a compression testing machine and loaded just to the crushing point. These data indicate that a vertical load of 20 G's could be tolerated without injury. The voluntary threshold line could probably be moved up to that value.

With no support, that is, no seat belt or shoulder harness, people were injured when subjected to 26 G's for about 0.04 second. When people were held by seat belts and shoulder harnesses, this exposure was tolerated without injury (A fig. 26). Current literature indicates that Swedish pilots have been ejected from high-speed airplanes with accelerations of 25 G's without injury. This information has not been verified, however.

If the restraining harness is increased to include chest and thigh straps and possible minor injury is acceptable, the limits increase to the dotted line. Pigs have tolerated 100 G's for about 0.002 second without injury and were completely normal in a day or two. The limit drops rapidly to 40 G's, however, as the duration is increased to 0.05 second. Above the limits defined by the dotted line, severe injury is probable.

Study of injuries caused by vertical loads show that vertical overloads on the spine frequently produce wedge-type fractures. These fractures occur when the vertebrae are loaded eccentrically.

Figure 27(a) shows two vertebrae in their normal position. The faces, A and A', are parallel. The intervening space is filled with cartilage. At B, the vertebrae overlap each other to keep the spine in alinement. There is an overlapping pair such as this on each side of each pair of vertebrae. 4149

When the spine is bent or kinked, the relative positions of the vertebrae are as shown in figure 27(b). The cartilage on one side is compressed. The overlapping alinement parts become separated. A heavy load on the vertebrae is concentrated on the outside corners. The cartilage crushes or squeezes out. The corners of the vertebrae shear off in a wedge shape. If the load is great enough, the alinement parts may also break. The vertebrae can then slide sideways, and a crushed or severed spinal cord results. Such an injury is, of course, very serious.

The manner in which the spine becomes kinked so that it is loaded to one side must be considered. Ordinarily, a seated person's spine is arranged as shown in figure 28(a). The spine as supported by the seat back forms practically a straight column. The column force from the spine is transferred through the pelvis to the seat. The contact point with the seat is not in line with the spine, however; thus there is a moment tending to twist the pelvis. Increasing the vertical load increases the twisting tendency. If the pelvis moves under this load, the lower part of the pelvis slides along the seat pan and the back of the pelvis slides down the seat back. The spinal column then buckles concentrating the vertical load on a smaller area of the vertebra involved (fig. 28(b)).

A longitudinal force component is generally present while the vertical force is being applied. Consequently, the momentum of the legs places an additional couple on the pelvis, and the weight of the legs also tends to rotate the pelvis about the seat belt (fig. 29). This couple increases the couple already twisting the pelvis and bending the spine.

There is also a third load transmitted to the spine. The horizontal load on the shoulder harness introduces a vertical load over the occupant's shoulder (fig. 30).

This vertical load is added to the two loads already imposed. If these combined loads are great enough, then wedge-type fractures, or worse, result.

Considering the manner in which these loads are applied to the spine, it appears that changing the military lap-belt - shoulder-harness combination might reduce the unit vertical load on the vertebrae. The addition of thigh straps (fig. 31) would keep the pelvis from tipping. This would keep the spinal column and pelvis vertical, keep the unit compressive loads on the vertebrae smaller, and increase the load the spine could carry. The animal data (fig. 26) show that this addition would increase the tolerance. Experimental human data are not available to prove this point, however. It seems that a chest strap could also remove some of the load on the spine. The chest strap would take some of the horizontal load off the shoulder harness. This would reduce the vertical component of the shoulder-harness load. If the strap were well up under the arm pits, it could also help support the vertical reaction of the arms and shoulders. Both of these remedies have been used by Lt. Col. Stapp to increase the tolerance to loads perpendicular to the spine. They may also be useful for loads parallel to the spine.

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For the transport passenger who wears only a seat belt, the situation is different. The occupant's motion as his upper torso flexes over the belt and strikes his knees and as his head snaps down affects the loads placed on these parts. One would expect first that there might be severe abdominal injuries because of the heavy belt load on the abdomen, or spinal injuries because of extreme bending of the spine.

The Aviation Crash Injury group of Cornell University has studied the injuries of 1000 survivors of 670 light plane crashes to determine whether the seat belt injures occupants, and if so, in what way (ref. 5). This study showed that decelerative forces of about 12 to 15 G's, the limit of the belt strength, can be tolerated with little likelihood of injury. Out of the 1000 survivors only about 1 percent had "lower torso injuries for which the safety belt could reasonably be considered as a direct cause". This 1 percent was composed of three cases of intra-abdominal injury, and six cases of lumbar-spinal injury. There are no data to show how much greater the deceleration could be without probable serious injury to the lower torso.

Next it is necessary to consider the occupant's tolerance when his chest hits his knees. The tolerance to decelerations perpendicular to the spine has been shown to be at least 45 G's for short intervals. It would be interesting to compare this value with the deceleration measured in the experimental crash in which the dummy flexed over its belt. In that crash, the first major impact occurred at a speed of about 100 miles per hour. The peak longitudinal deceleration measured on the floor was about 18 G's. The deceleration of the dummy's chest perpendicular to its spine when its chest hit its knees was 52 G's. The chest deceleration then was about three times that of the floor. If a 45 G limit is accepted for accelerations perpendicular to the spine, it appears that the limit a human can tolerate with a belt alone may be about 15 G's.

Finally, consider the head and neck. Linear decelerations of 45 G's without a head support have been survived. With a seat belt, however, there is a rotary motion in addition to the linear forward motion. There is, therefore, a centrifugal force imposed on the neck in addition to the force from the snap when a person's chest strikes his knees. In the example of the dummy's action (fig. 19), this centrifugal force was about 560 pounds. The dummy's head also had, because of its velocity, a kinetic energy of about 700 foot pounds. (Since the dummy's weight distribution was similar to that of a human being, the centrifugal force and kinetic energy would be the same for a passenger.) This energy must be dissipated in a very short time and distance as the passenger's head snaps down and stops. This stopping force would be rather large. For comparison purposes, when a person is executed by hanging, he is dropped about 6 feet. If a 170-pound man is assumed, there is an energy level of about 1020 foot pounds when the rope stops him. Comparing this value with the combination of 700 foot pounds of kinetic energy and 560 pounds of centrifugal force just discussed, it appears that the limit is being approached.

Considering the entire upper part of the body, then, it seems that exposure to a deceleration of more than 15 to 20 G's when being held by only a seat belt may be dangerous. The kinetic energy accummulated by the head can be considered to reduce the over-all tolerance to fore and aft decelerations.

SUMMARY OF RESULTS

The results of this study of experimental and accidental crashes to determine the mechanisms of crash injury are summarized as follows:

1. Airplanes whose forward compartments can bend upward when the belly strikes the ground in a crash and so avoid being crushed between the main bulk of the airplane and the ground, and whose lower structure can tear free along the floor line so that compartments are not pulled down under the sliding hulk, are less likely to crush the occupants.

2. The collapse of seats and other structures can trap occupants and prevent escape or hinder rescue even though the occupant is not severely injured.

3. Attachment fittings for cabin equipment can fail and allow the equipment to become lethal missiles.

4. The hazards of flying propeller parts and the front landing gear can be circumvented by placing unoccupied compartments in the paths of these missiles.

5. People held by seat belts alone can strike obstacles while flailing about in a crash, and the energy available in the head can be several times that required to produce a simple skull fracture.

6. A human being can tolerate decelerative loads of 45 G's perpendicular to the spine, and 20 G's of compressive load parallel to the spine if adequately supported.

7. Additional restraining harnesses to keep the spine in proper alinement may hold the occupant in a better position to withstand vertical blows.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, June 20, 1956

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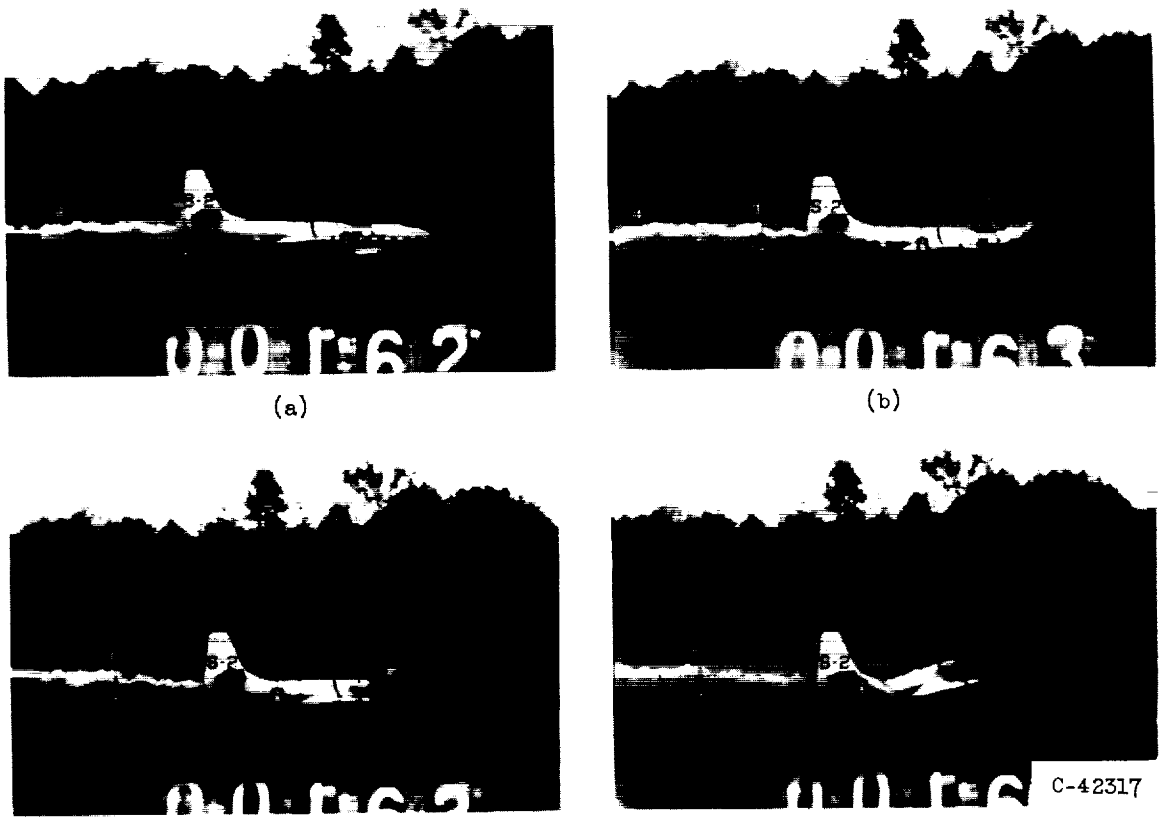

(a) (b) (c) (d)

Figure 1. - Crushing of nose and cockpit structure in fighter airplane crash.

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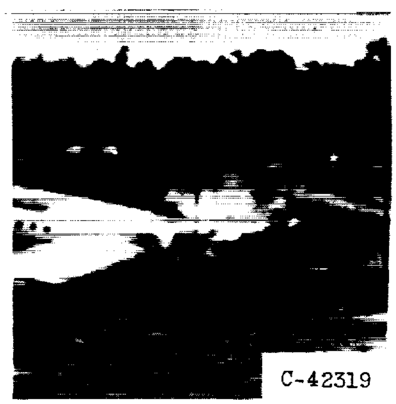
(a) Hinging movement beginning.

(b) Movement clearly noticeable.

(c) Movement approaching maximum.



(d) Maximum hinging movement.

Figure 2. - Hinging action of crew compartment.

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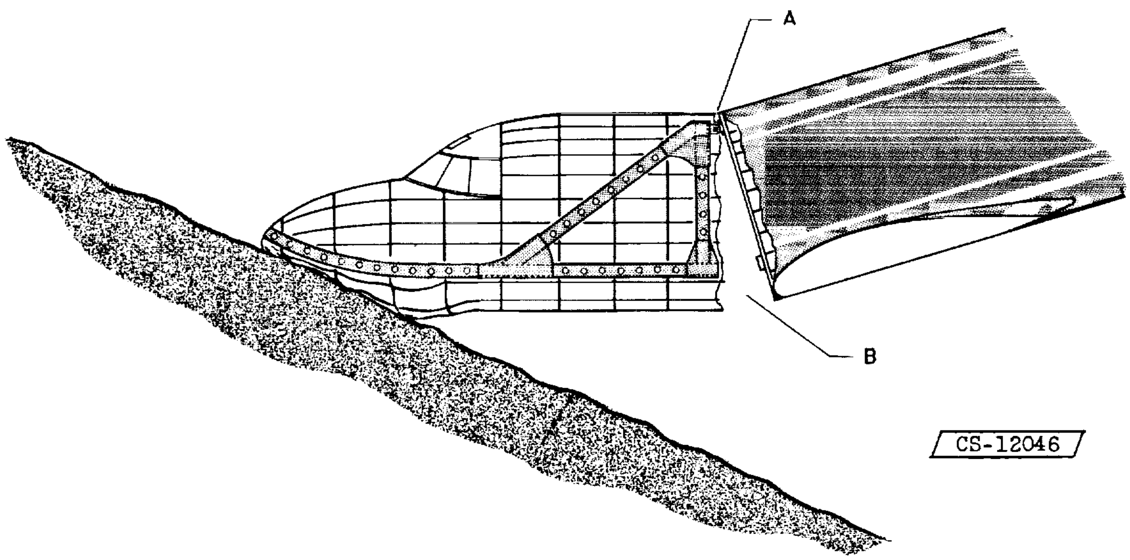

Figure 3. - Crush-resistant cabin lifting at impact.

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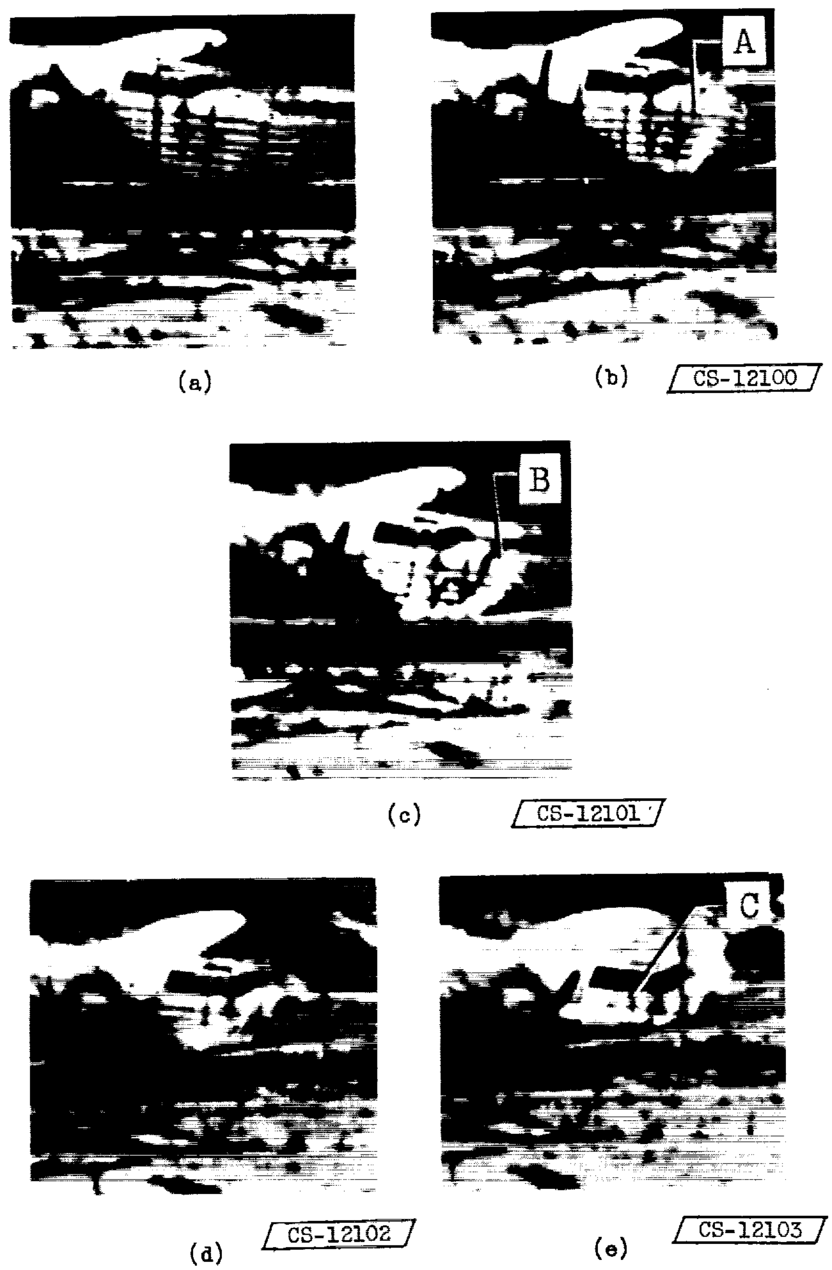

Figure 4. - Successive stages of fuselage structure being pulled under sliding airplane.

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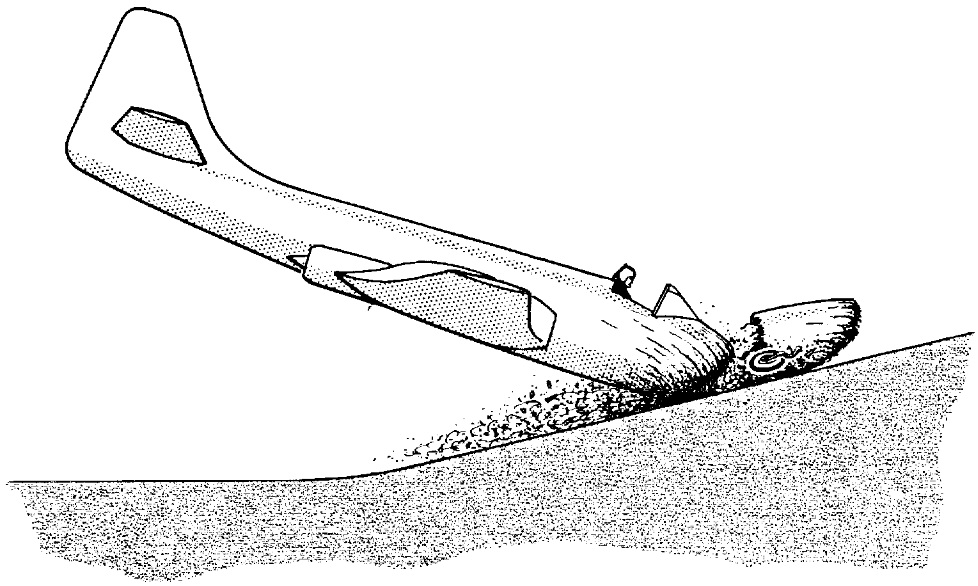

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Figure 5. - Destruction of pilot's compartment.

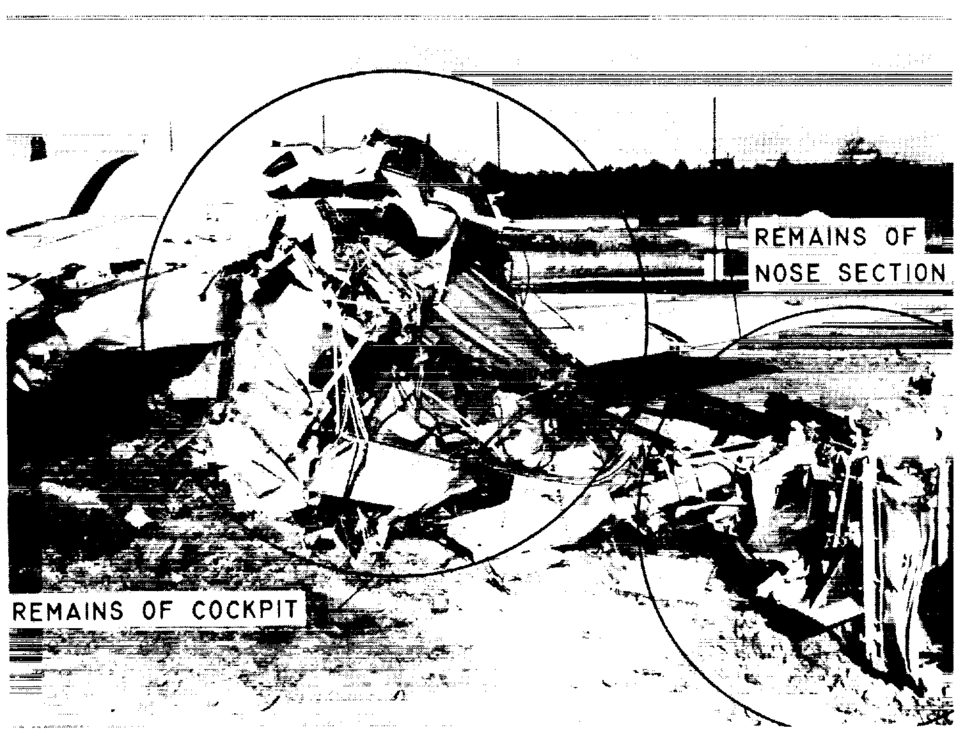

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Figure 6. - Front fuselage structure nearly pulled under sliding airplane.

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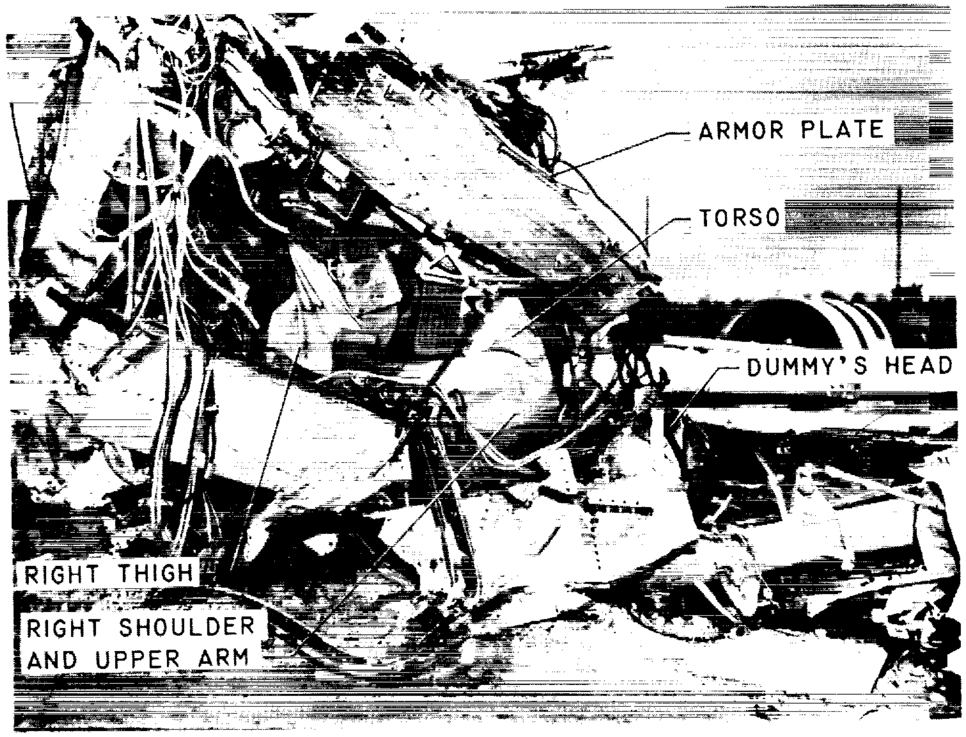
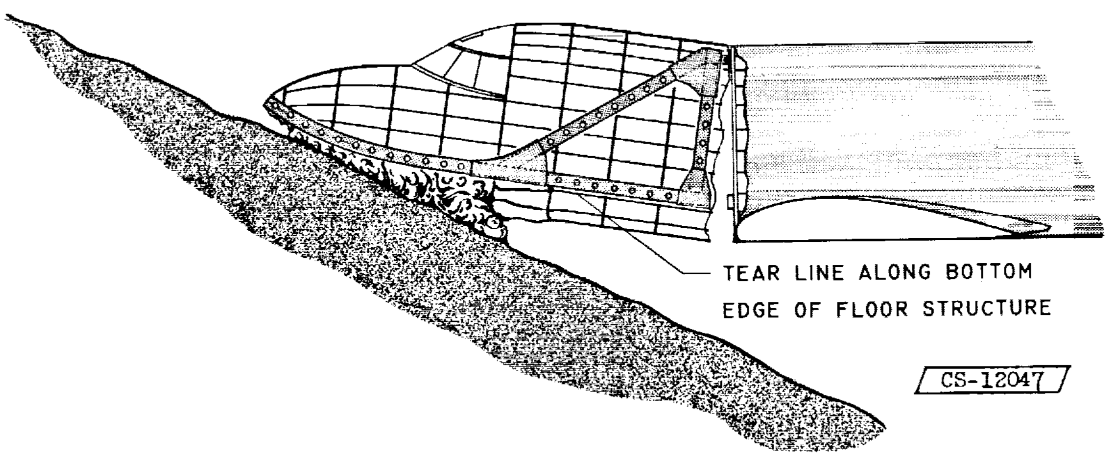
CD-3 back



CS-12038

Figure 7. - Close-up of front fuselage structure nearly pulled under sliding airplane.



CS-12047

Figure 8. - Crush resistant cabin with understructure tearing away.

4149

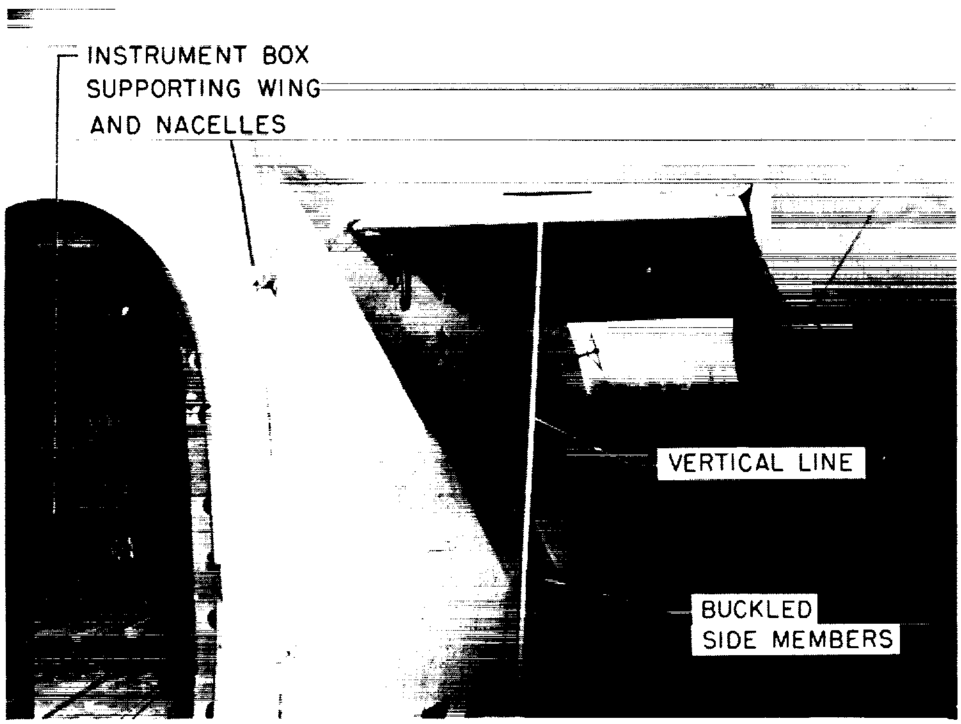


Figure 9. - Airplane with rectangular cross section after ground-loop crash.

CS-11888

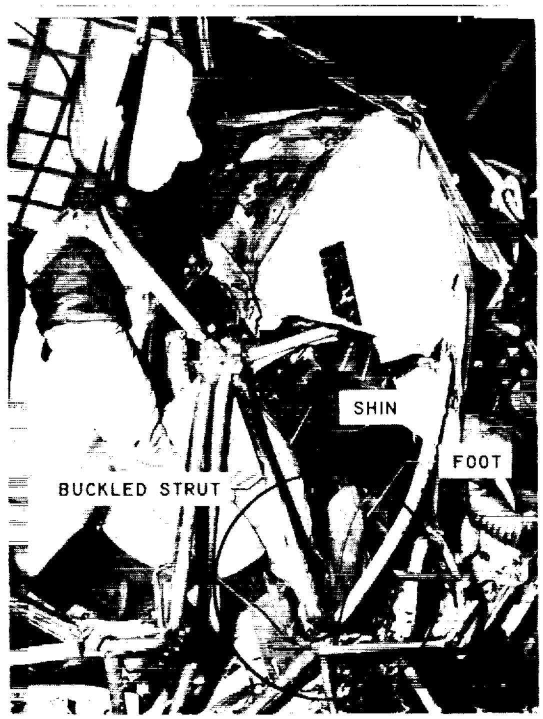
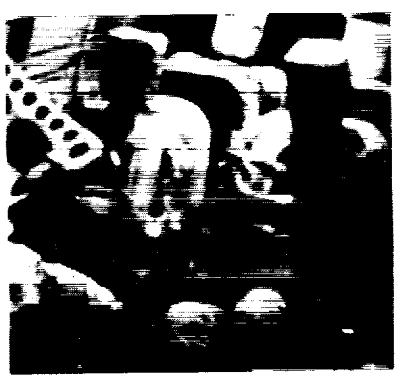


Figure 10. - Foot trapped by bent structural brace.

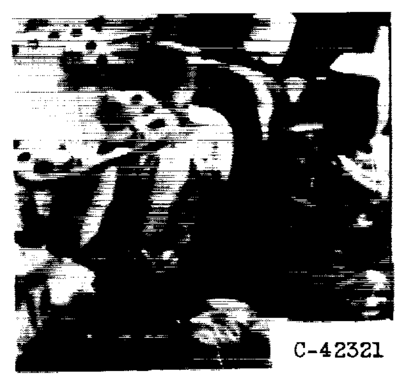
CS-12037

(a) Dummies instant before impact.

(b) Escape hatch moving.



(c) Escape hatch approaching dummy.



(d) Escape hatch striking dummy.

Figure 11. - Escape hatch striking dummy.

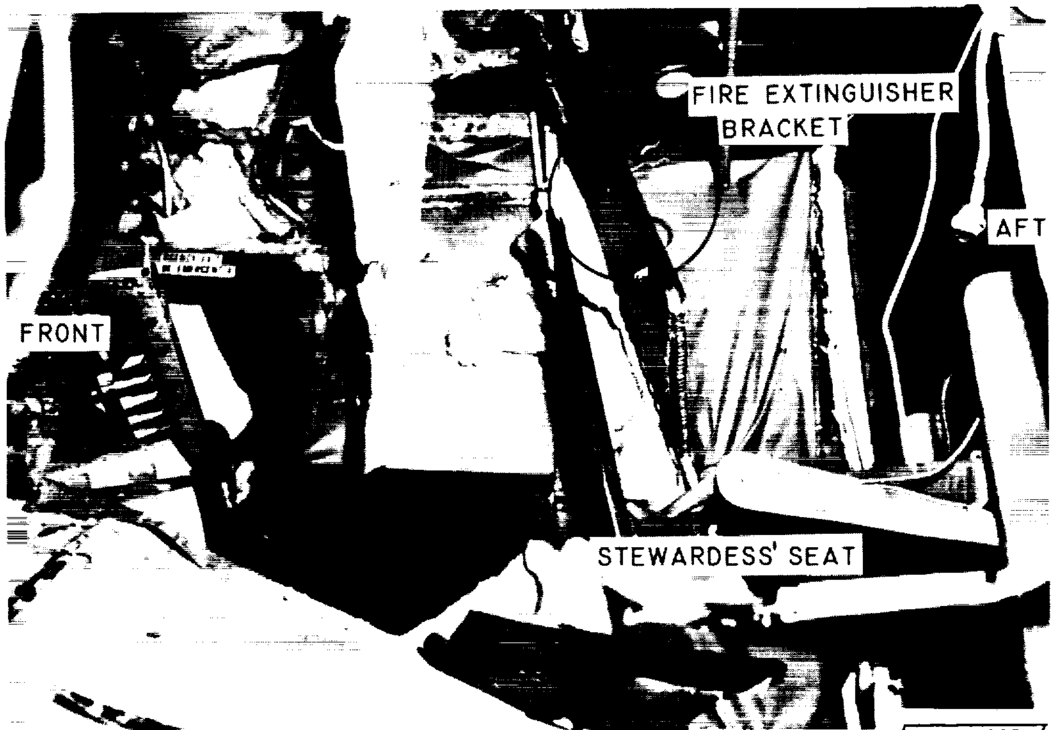


Figure 12. - Empty bracket for fire extinguisher which broke away and struck stewardess.

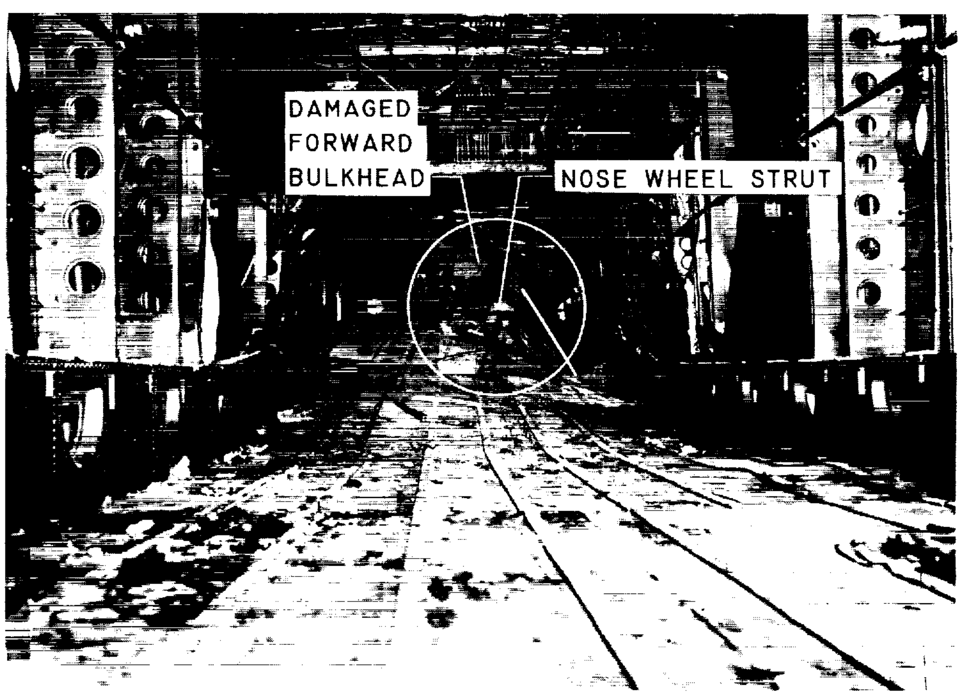


Figure 13. - Nose gear driven into cabin. CS-12099

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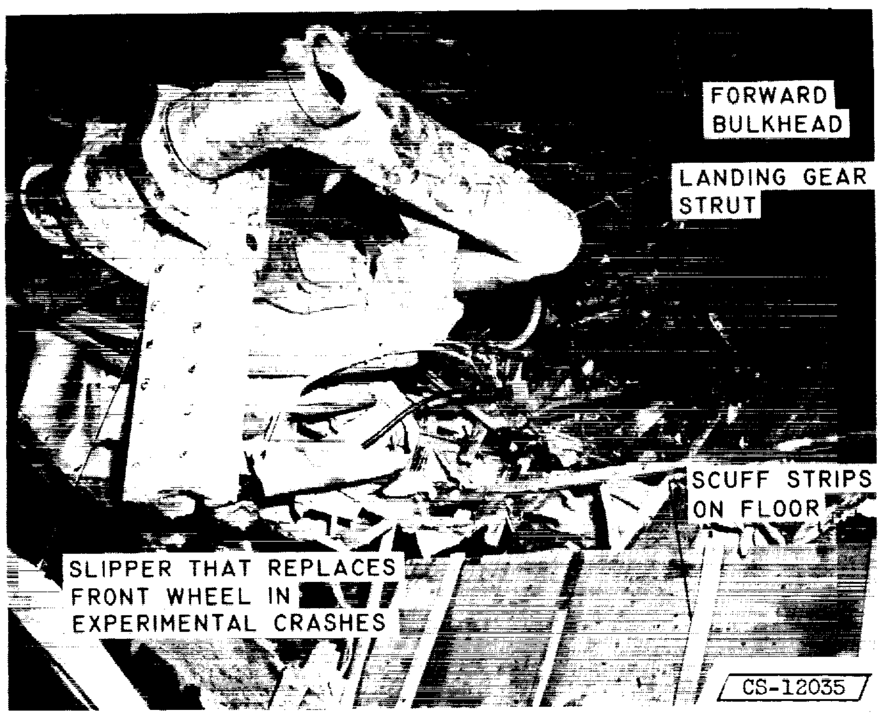

Figure 14. - Front landing gear strut and guide slipper (replaces nose wheel) driven through floor by crash impact.

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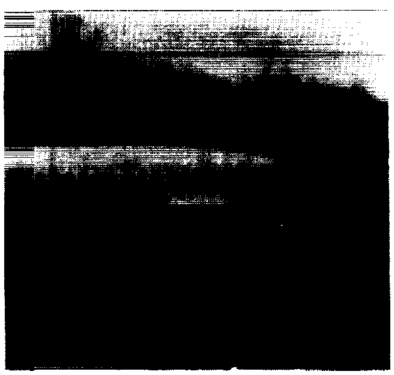
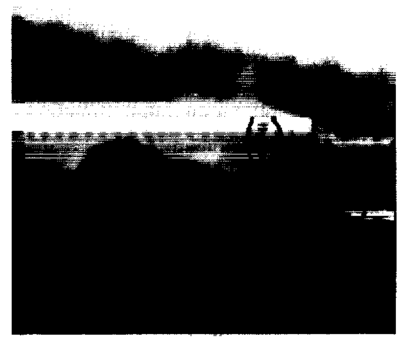
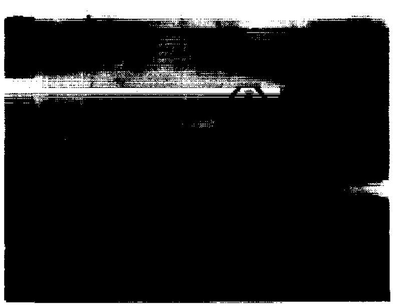


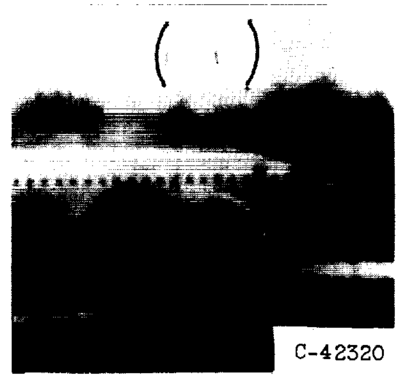
(a) Fuselage before blades strike obstacle.



(b) Blades being detached.



(c) Hole cut in fuselage by blades.



(d) Three blades visible against sky.

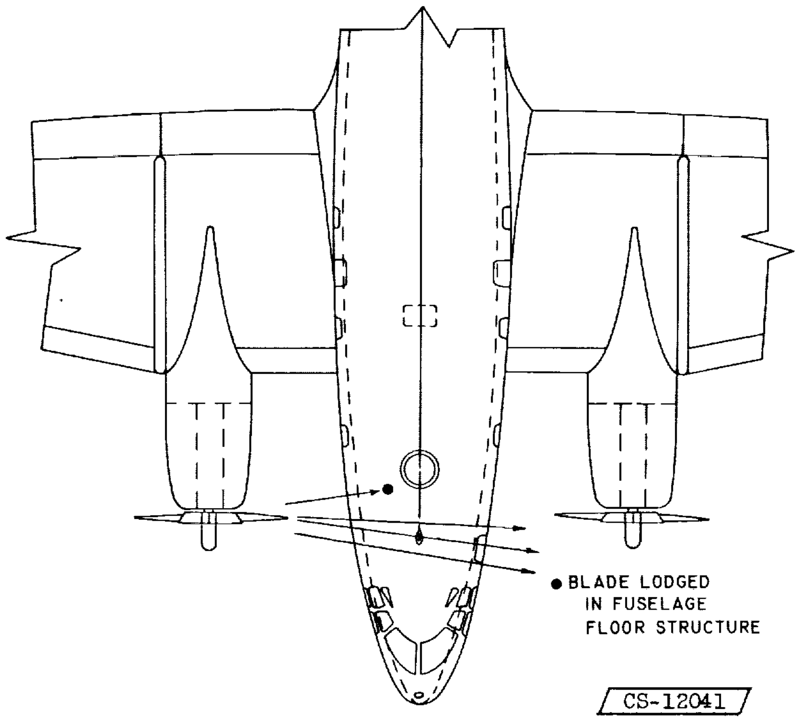
Figure 15. - Fuselage damaged by detached propeller blades.

4149

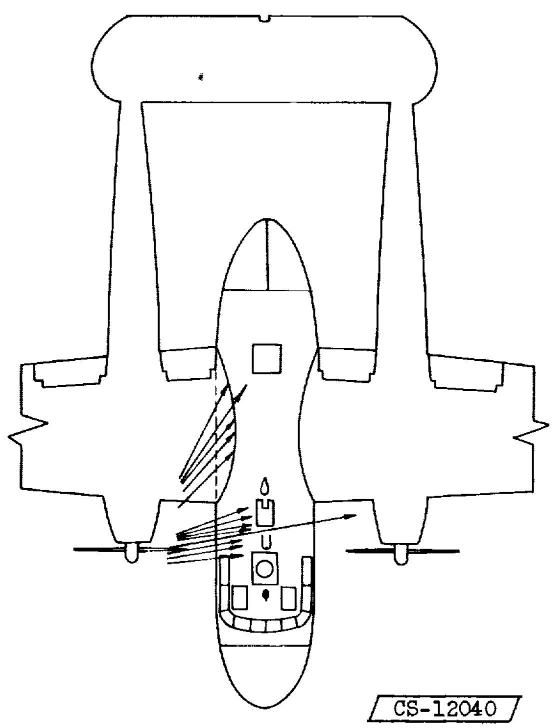
CD-4

Figure 16. - Hole cut in fuselage by propeller blades. CS-12051

4149



(a) Penetration by steel propeller blades during four crashes.



(b) Penetration by forged aluminum propeller fragments during fourteen crashes.

Figure 17. - Propeller blade penetration of fuselage.

4149

CD-4 back

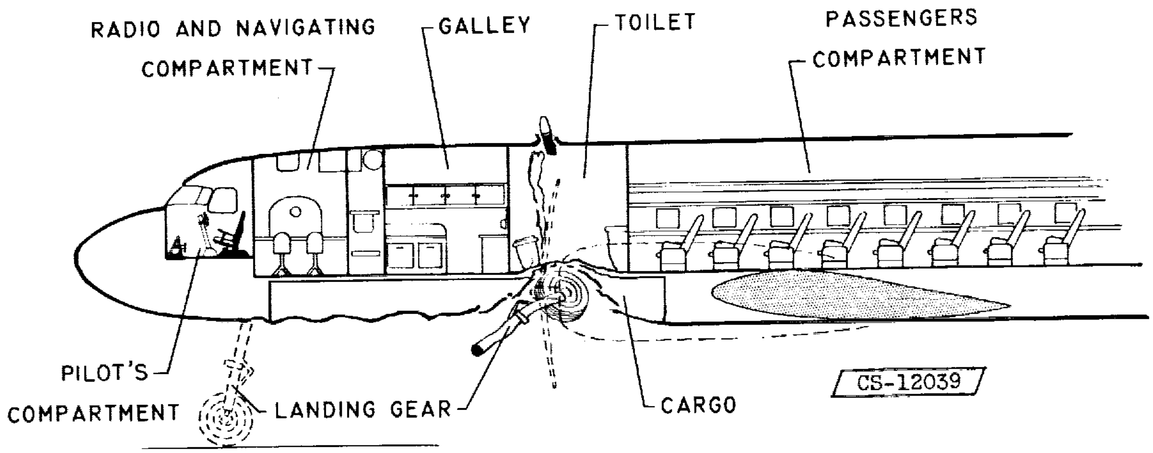


Figure 18. - Cargo and unoccupied zones placed in path of front landing gear and propeller fragments.

4149

(a) Position at instant of impact.

(b) Torso bent forward.

(c) Torso approaching knees.

(d) Head snapped down between knees.

Figure 19. - Flailing action of dummy.

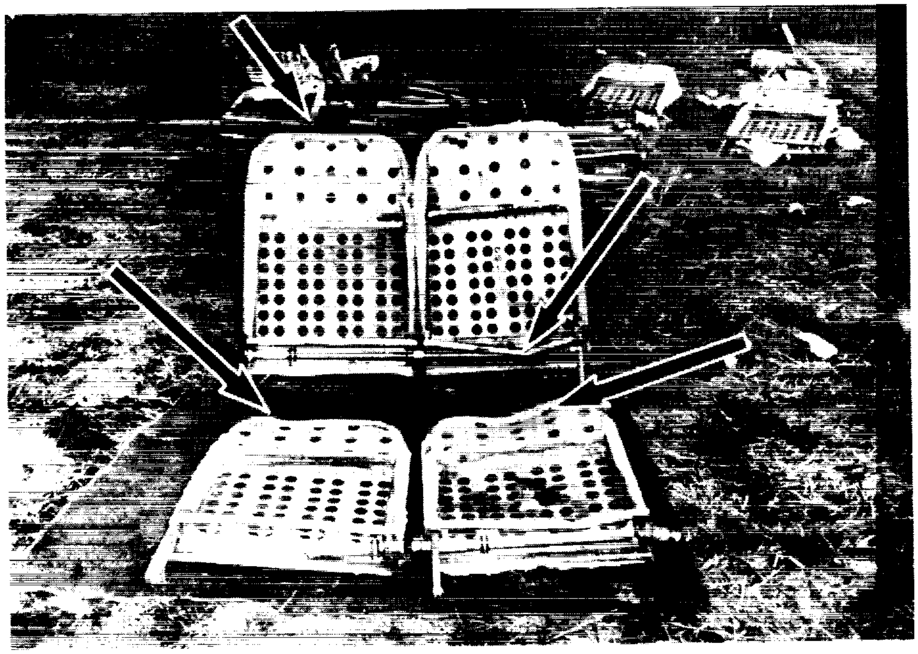
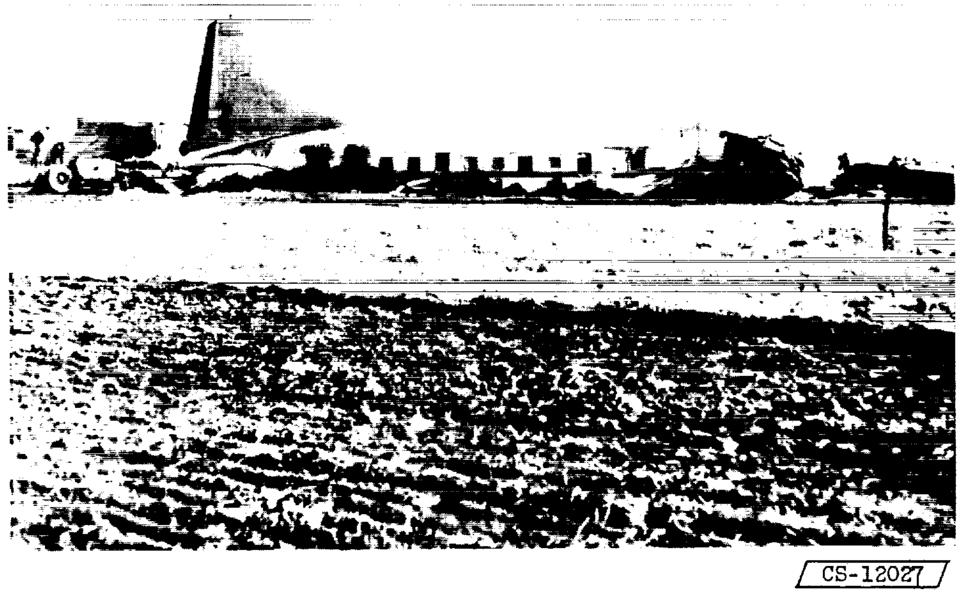

CS-12031

Figure 20. - Seat backs made of easily deformed metal which protect passengers from impact injury. (Photograph supplied by Aviation Crash Injury group of Cornell University.)


CS-10219

Figure 21. - Failed seats torn loose and piled in front of cabin.

4149



(a) Aft fuselage structure.

(b) Interior view looking forward at cabin floor structure.

Figure 22. - Crash in which impact forces destroyed seat attachment fittings. (Photographs supplied by Aviation Crash Injury group of Cornell University.)

4149

(c) Seat wreckage assembled in original rows.

Figure 22. - Concluded. Crash in which impact forces destroyed seat attachment fittings. (Photographs supplied by Aviation Crash Injury group of Cornell University.)

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CS-12032

Figure 23. - Spear-like point formed by broken seat back tubing. (Photograph supplied by Aviation Crash Injury group of Cornell University.)

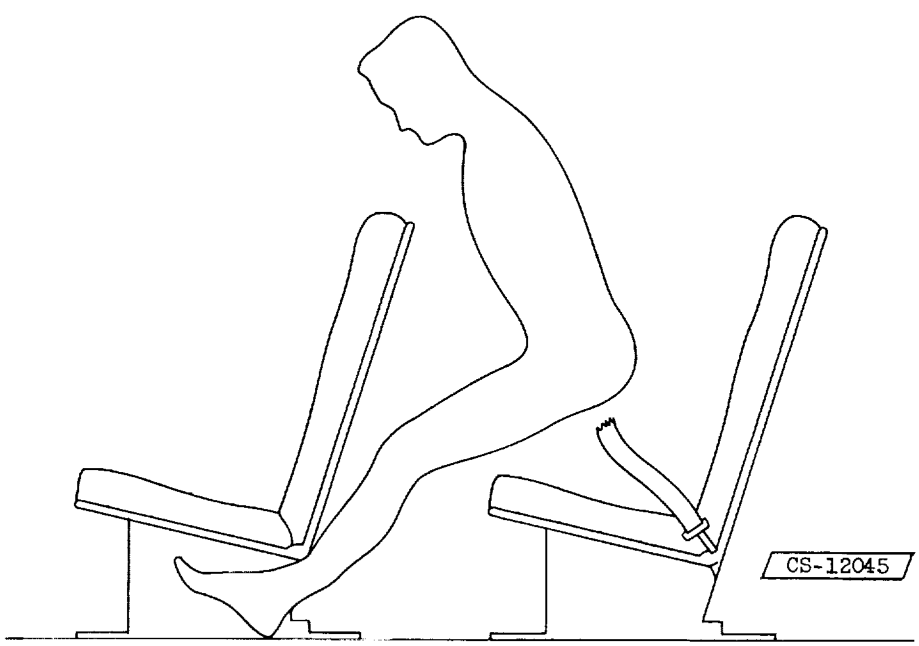

CS-12045

Figure 24. - Shanks broken by lever action.

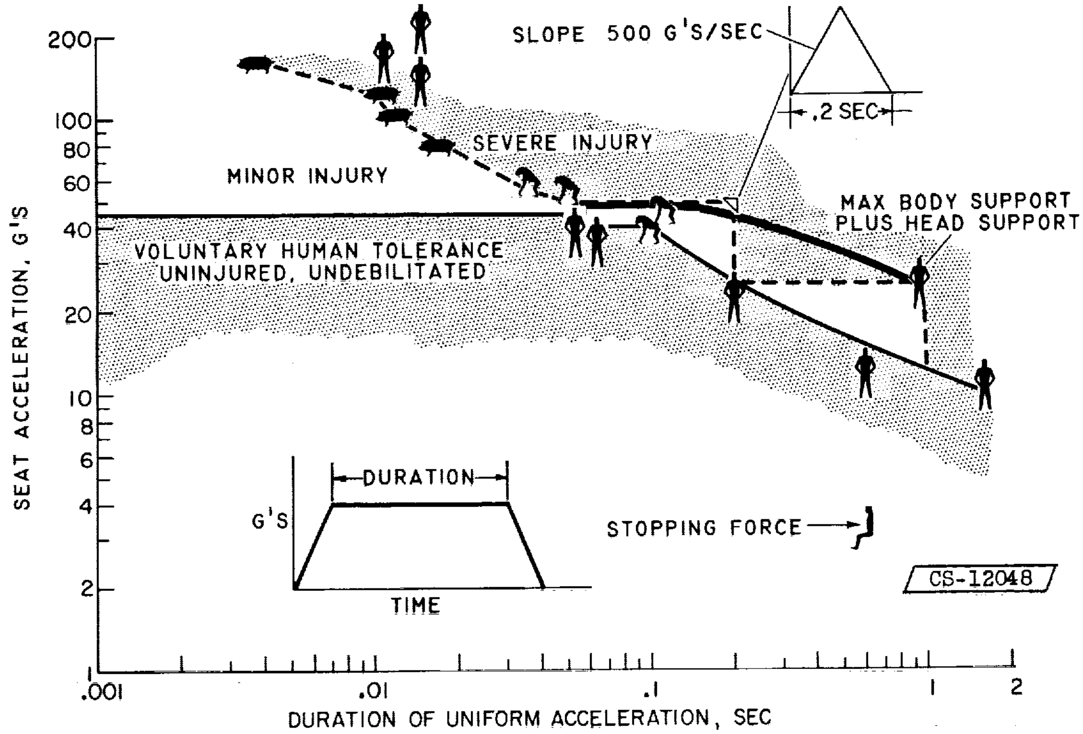


Figure 25. - Tolerance to acceleration perpendicular to spine with maximum body support.

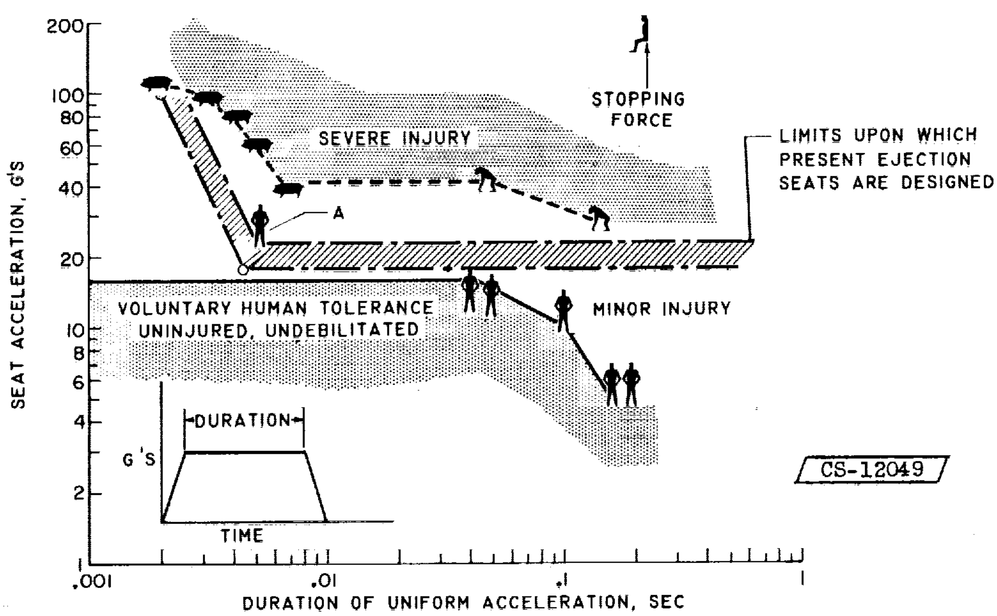
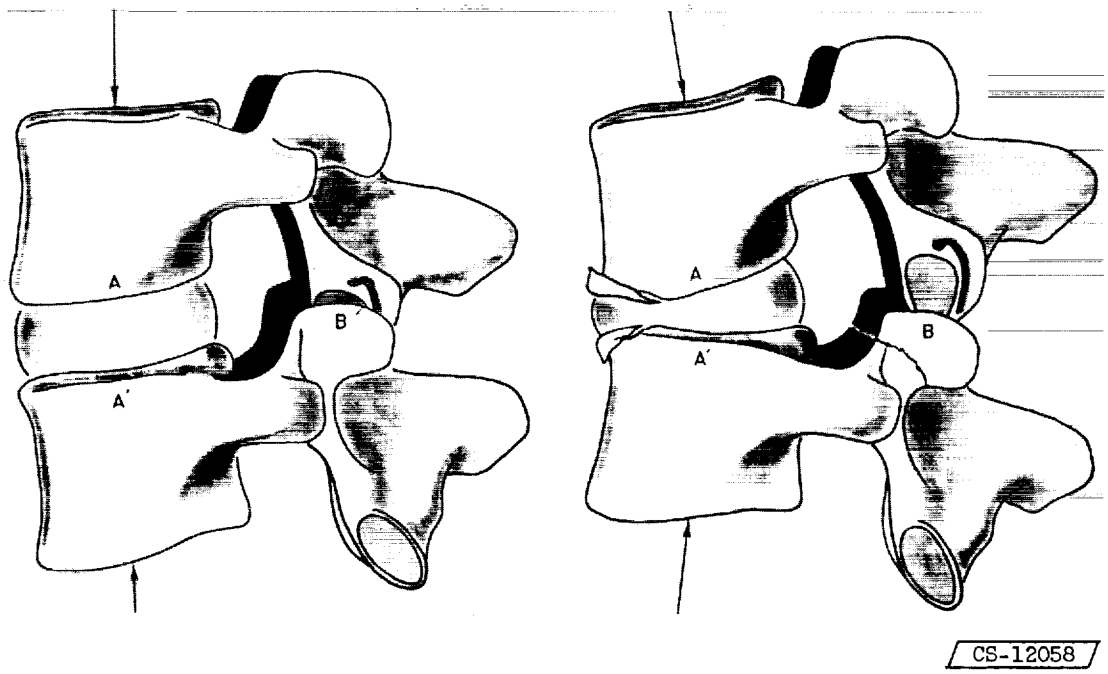
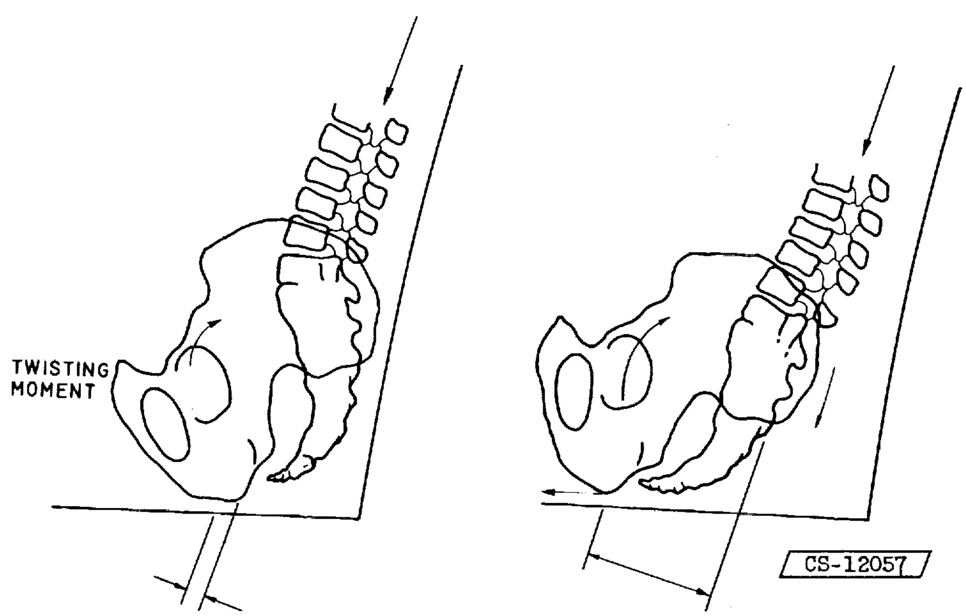


Figure 26. - Tolerance to acceleration parallel to spine with lap belt and shoulder harness.



(a) Vertebrae in normal position. (b) Vertebrae in flexed position.

Figure 27. - Mechanism of spine fractures.



(a) Spine in normal position. (b) Spine in flexed position.

Figure 28. - Effect of vertical load on spine and pelvis.

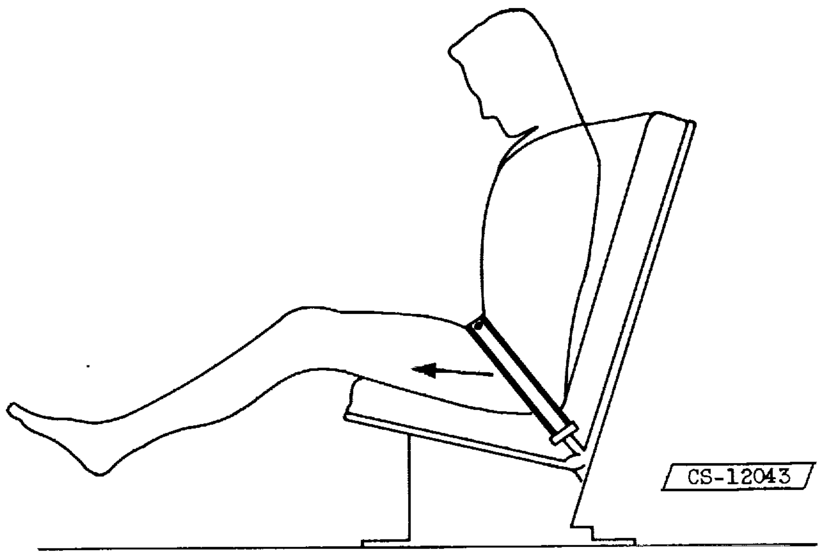


Figure 29. - Reaction of thighs, shanks, and feet on pelvis.

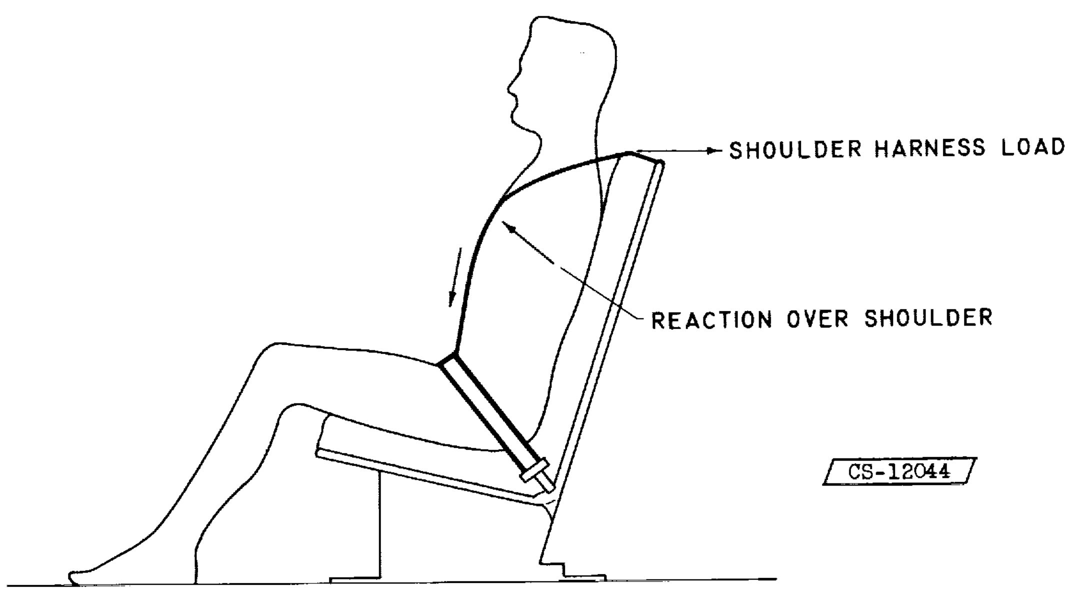


Figure 30. - Vertical reaction of shoulder harness on spine.

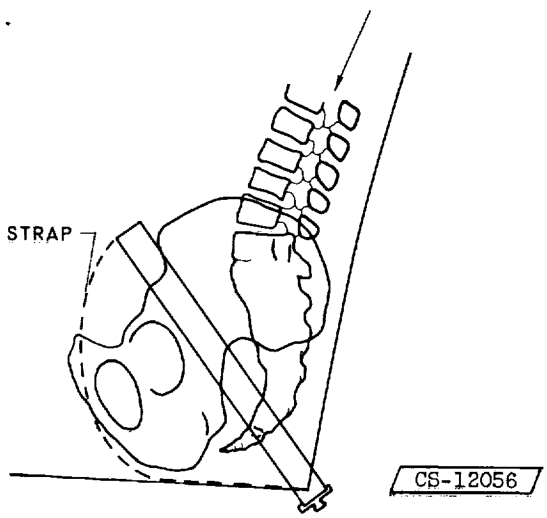


Figure 31. - Effect of thigh strap on spine and pelvis.

NACA TN 3775
National Advisory Committee for Aeronautics.
CRASH INJURY. Gerard J. Pesman and A. Martin Eiband. November 1956. 36p. diagrs., photos. (NACA TN 3775)

Data from full-scale experimental airplane crashes were studied to determine how impact injuries occur and how the chance of such injuries may be reduced. The following hazards were considered: (1) being crushed, (2) being struck by missiles, (3) striking objects by tearing loose or flailing about, and (4) being injured by the crash decelerations. Transport, cargo, fighter, and light airplane crashes were studied.

Copies obtainable from NACA, Washington

1. Airplanes (1.7.1)
2. Airplanes - Components in Combination (1.7.1.1)
3. Loads (4.1)
4. Loads, Landing - Impact (4.1.2.1)
5. Operating Problems (7)
6. Safety (7.1)
I. Pesman, Gerard J.
II. Eiband, A. Martin
III. NACA TN 3775

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